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THE PHYSICAL SETTING OF THE CHILEAN BORATE DEPOSITS

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North of the Tropic of Capricorn, the Andes of Chile and Bolivia stand forth as two massive chains with a lofty plateau between. The two great ranges of Andes are known as the Cordillera Occidental and the Cordillera Oriental, or Cordillera Real. The lofty tableland between passes under the name of Altaplanicie, or Great Central Plateau of Bolivia. It is in some respects one of the most remarkable topographic features of South America. Throughout nearly ten degrees of latitude its surface maintains an elevation of approximately 12,000–13,000 feet above sea-level. But apart from its greater elevation this broad inter-Andine tableland shows a resemblance to portions of the great basin region in the western United States.

This plateau is boxed in on the east by the great wall-like ridge of the Eastern Cordillera which culminates in the giant peaks of Illimani (21,200 feet) and Illampu (21,490 feet). On the west the plateau is bounded by a remarkable string of volcanoes which constitute the Western Cordillera. The two systems of mountains are totally unlike. While the eastern range, or Cordillera Real, is composed of folded Paleozoics, with the still older granites and gneisses exposed in the axis of the range, the Western Cordillera is conspicuous chiefly as a chain of volcanic cones perched upon the western edge of the great plateau. These volcanic cones rest upon folded Mesozoic strata, chiefly of Jurassic and Cretaceous age. The body of the plateau itself is composed principally of beds ranging in age from the Devonian to the Cretaceous.

Throughout the extent of the plateau, in Chile, Bolivia, and Peru, are numerous lakes, saline marshes, and beds of former lakes, most of which possess no outward drainage. The large bodies of water which still persist, like Lake Titicaca and Lake

Pampa Aullagas, are well enough known, but in addition there are many minor lake flats, dry or nearly so, which escape notice. It is on some of these old lake bottoms that the great borate deposits of South America occur. But here the geographic distribution of the lakes which contain borax is of significance, as it is found that the deposits of borax are largely confined to those lakes which lie close to the volcanoes of the Western Cordillera. Away from the volcanoes, whether eastward over the central plateau, or westward down the long desert slopes leading toward the coast where the nitrate beds abound, the borates rapidly disappear. The borates thus seem to be related to the volcanoes. The nitrates occur on open salinas at moderate elevations, 3,000–5,000 feet, and not far back from the coast. The borax fields, on the other hand, are located high up on the edge of the tableland close to the base of the big volcanoes. Both nitrates and borates are dependent for their accumulation and preservation upon the extreme aridity of the region, but the sources of the nitrogen and the boron are quite different.

The Salinas of Ascotan may be taken as a typical case to show the probable source of the borates. The railroad from Antofagasta to Bolivia creeps steadily upward from the coast and reaches its highest point in crossing the Western Cordillera at the station of Ascotan, which is about 13,000 feet above the sea. The Western Cordillera here consists of volcanoes most of which have only recently become extinct, while, from a few, smoke is still escaping. In the neighborhood of Ascotan the cones rise to heights of 17,000–19,500 feet. But in spite of the great altitude only an occasional patch of snow is seen on these lofty peaks owing to the extremely scanty precipitation, for this region lies at the northern end of the desert of Atacama.

After climbing up to Ascotan the railway runs parallel to the line of volcanoes and the great borax lake of Ascotan comes into view. This lake is perhaps 10 miles long and 3 miles wide, extending northward parallel to the range to a point beyond Cellobar. It fringes the base of a line of volcanoes which begin at the south in the cone of San Pedro y Pablo (19,400 feet) and end north of the lake in the smoking volcano of Ollagüe (19,200 feet). The slopes of the volcanic cones rise directly from the shores of the borate lake. In the so-called lake very little water is seen; most of its surface is a white field of borate which rests upon the watery mass below like ice upon a partially frozen pond. It is really a borate incrusted lake bed.

The craters of the adjoining volcanoes are all quite recent, and some of them are probably dormant rather than extinct. Ollagüe at least still emits a thin thread of smoke from an orifice in its upper slopes. Drainage lines are not yet well established, but whatever drainage and seepage there may be from these cinder cones would necessarily pass, in large part, directly into this lake basin. Underground drainage from several large volcanoes would find its way into the borax lake. One of the craters was seen to have its wall broken down on the side toward the lake so that much of the surface runoff from the crater walls as well as the underground seepage through the cinder cone would go directly to the lake (Fig. 1).

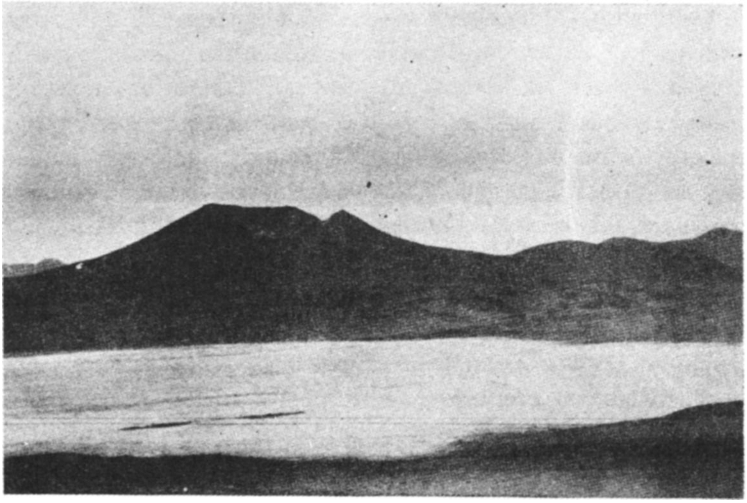

FIG. 1.—Volcano on border of Ascotan Borax Lake. The drainage from the crater passes directly into the lake.

The lake has no apparent outlet so that the small amount of water on the lake bed represents a state of balance between the scanty precipitation which falls upon the basin and its volcanic borders, and the loss by evaporation. Necessarily there is a concentration of salts as evaporation goes on. All salts dissolved by waters which trickled through the volcanic cones and reached the lake flat would gradually become concentrated there as the water evaporated and would finally be deposited as a solid incrustation.

The water entering the lake, whether directly or by the underground route, can have come in contact with little besides volcanic material, since all the higher land around the lake is made up of volcanic rocks. Therefore the source of the boron is to be sought in the volcanoes. Unfortunately lack of time did not permit an examination of the craters themselves. But it is known that borates and free boric acid in the form of sublimates from hot vapors are often conspicuous deposits around fumaroles and active volcanic craters in various other parts of the world. Judd states that in the solfataras of Tuscany, boracic acid is, next to the true gases, the most noteworthy compound emitted from the vents.[1] Vulcano, in the Lipari Islands, emits boracic acid which, attacking the materials of the surrounding rocks, has formed borates of the alkalies and alkaline earths.[2] These new chemical compounds are continually accumulating on the sides and lips of fissures from which the acid gases and vapors are issuing. The mineral sassolite ($B_2O_3.3H_2O$) is common at Vesuvius.[3] Compounds of boron are therefore to be expected in these Chilean volcanoes and it may be supposed that rain-water falling upon these craters and percolating through the cinder cones would dissolve the soluble boron salts and later deposit them on the lake bed where the water finally evaporated.

But in addition to borates, other salts soluble in water, such as chlorides, sulphates, etc., are also present in volcanic craters. These should also be dissolved by rain-water and carried down onto the evaporating flat as well as the borates. This has evidently happened in the Ascotan field, for the percentage of borate varies considerably in different parts of the area. The boron, however, occurs almost entirely as a single compound, the mineral ulexite, or boronatrocalcite ($NaCaB_5O_9.8H_2O$). But there would seem to be in operation some process by which the various salts derived from the volcanoes are separated before being deposited on the lake flats, for in some parts of the field the boronatrocalcite occurs remarkably pure. It is in such places that it is now being worked for borax. The material is so free from other salts that it is only necessary to dry it before shipping it to Europe, where it is later refined. But in other parts of the region the borate occurs in beds alternating with layers of salt and salty earth with some glauberite and gypsum associated.

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[1] J. W. Judd, *Volcanoes*, p. 216.

[2] *Ibid.*, pp. 42–44.

[3] J. L. Lobley, *Mount Vesuvius*, p. 321.

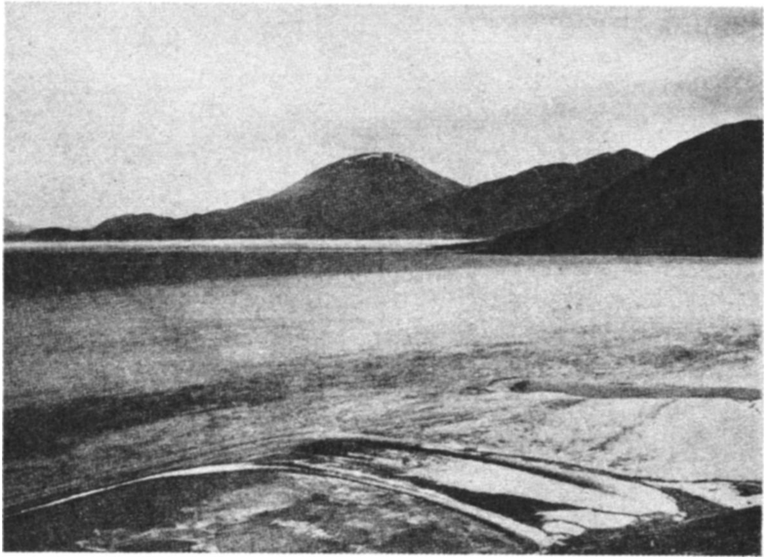

FIG. 2.—Borax incrusted lake flat with the volcano Ollagüe in the distance. Other volcanic peaks to the right.

Some distance beyond Cellobar is another dazzling white bed of borax whose flatness the railroad to Bolivia utilizes by running straight across it. Close by is the big volcano Ollagüe which is still smoking (Fig. 2). On other sides the borax flat is hemmed in by several scarcely less massive cones which would seem to provide ample sources for the borate in the basin.

Beyond the station of Ollagüe the train, turning more to the east, leaves the volcanic Cordillera and makes its way over the Great Central Plateau to Uyuni and Oruro. This region is a great detritus-strewn plain with low ridges and ranges trending generally north and south. Salt marshes and old lake beds continue, but as the volcanoes are left behind, the deposits of borax rapidly disappear. There are no known borate deposits associated with the non-volcanic Eastern Cordillera.